Attorney Docket No. 2003P04912US-01

VALVE APPARATUS

Cross Reference to Related Applications

[0001] This application claims the benefit of the earlier filing date of U.S. Provisional Application No. 60/460,510, filed 4 April 2003, U.S. Provisional Application No. 60/547,829, filed 26 February 2004, and U.S. Provisional Application No. 60/548,813, filed 27 February 2004, all of which are incorporated by reference herein in their entirety.

[0002] Related co-pending applications filed concurrently herewith are identified as "System and Method of Managing Pressure in a Fuel System" (Attorney Docket No. 2004P03148US-01), "Sealing Liquid for a Valve Apparatus" (Attorney Docket No. 2004P03254US-01), and "Housing for Valve Apparatus" (Attorney Docket No. 2004P05365US), each of which was filed 5 April 2004, and all of which are incorporated by reference herein in their entirety.

Field of the Invention

[0003] A fuel vapor pressure management apparatus that manages pressure and detects leaks in a fuel system. In particular, a fuel vapor pressure management apparatus using a liquid seal valve that vents positive pressure, vents excess negative pressure, and uses evaporative natural vacuum to perform a leak diagnostic.

Background of the Invention

[0004] A known fuel system for vehicles with internal combustion engines can include a canister that accumulates fuel vapor from a headspace of a fuel tank. If there is a leak in the fuel tank, the canister, or any other component of the fuel system, fuel vapor could escape through the leak and be released into the atmosphere instead of being accumulated in the canister. Various government regulatory agencies, e.g., the U.S. Environmental Protection Agency and the Air Resources Board of the California Environmental Protection Agency, have promulgated standards related to limiting fuel vapor releases into the atmosphere. Thus, it is believed that there is a need to avoid releasing fuel vapors into the atmosphere, and to provide an apparatus and a method for performing a leak diagnostic, so as to comply with these standards.

[0005] In such known fuel systems, excess fuel vapor can accumulate immediately after engine shutdown, thereby creating a positive pressure in the fuel vapor pressure management system. Thereafter, a vacuum in the fuel vapor pressure management system can result from natural system cooling after the engine has been turned off. Excess negative or positive pressure in closed fuel systems can occur under some atmospheric and operating conditions, thereby causing stress on components of these fuel systems.

[0006] An automotive on-board diagnostic (OBDII) can perform a leak detection test to determine if there is a leak in the fuel vapor pressure management system, which includes the fuel tank head space, the canister that collects volatile fuel vapors from the head-space, a purge valve and any associated hoses. A vacuum sensing function can perform the leak detection diagnostic. For example, a pressure/vacuum sensor or switch will allow the engine computer to monitor the vacuum that is caused by natural system cooling after the engine has been turned off, and thereby perform the leak detection diagnostic.

[0007] A vacuum relief function can provide fail-safe operation of the purge flow system, when the engine is ON, and guarantee that vacuum levels in the fuel tank do not endanger the integrity of the tank, when the engine is OFF. In general, the vacuum relief function should only allow flow at a pressure level below the vacuum sensor level.

[0008] A pressure relief function is desirable in order to "blow-off" the positive pressure due to excessive fuel vapor in the fuel vapor pressure management system immediately after engine shutdown. This can facilitate, e.g., expedite, the creation of the vacuum that is caused by the natural system cooling. Another benefit of the pressure relief function is to allow air to exit the tank at high flow rates during tank refueling. This function is commonly known as Onboard Refueling Vapor Recovery (ORVR). In general, the pressure relief function should be at a very low-pressure level in order to minimize the backpressure during refueling, and to limit excess pressure in a hot system.

Summary of the Invention

[0009] The present invention provides a valve apparatus that includes a housing that defines an interior chamber, a liquid that separates the interior chamber into first and second portions,

and a sensor. The housing includes first and second ports that communicate with the interior chamber. The first portion of the interior chamber is in fluid communication with the first port, and the second portion of the interior chamber is in fluid communication with the second port. And the sensor is disposed in the interior chamber.

[0010] The present invention also provides a bi-directional valve apparatus including first and second vapor flow paths. The first vapor flow path extends from a first port, through a liquid, to a second port. The second vapor flow path extends from the second port, through the liquid, to the first port. Vapor flow along the first vapor flow path occurs when there is a first pressure differential between the first and second ports, and vapor flow along the second vapor flow path occurs when there is a second pressure differential between the first and second ports.

[0011] The present invention further provides a method of managing vapor pressure. The method includes locating a chamber in vapor communication between first and second ports, disposing within the chamber a liquid separating the chamber into first and second portions, displacing a first volume of the liquid from the first portion of the chamber to the second portion of the chamber in response to a first negative pressure differential between the first and second ports, displacing a second volume of the liquid from the first portion of the chamber to the second portion of the chamber in response to a second negative pressure differential between the first and second ports, and displacing a third volume of the liquid from the second portion of the chamber to the first portion of the chamber in response to a positive pressure differential between the first and second ports. The second volume is greater than the first volume, and the second negative pressure differential is greater than the first negative pressure differential.

Brief Description of the Drawings

[0012] The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate presently preferred embodiments of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention.

[0013] Figure 1 is a schematic illustration of a fuel system that includes a fuel vapor pressure management apparatus in accordance with the detailed description of certain preferred embodiments.

[0014] Figure 2A is a top view of a model illustrating the operating principles of a vapor pressure management apparatus according to the present invention.

[0015] Figure 2B is an elevation view showing the resting state of the model shown in Figure 2A.

[0016] Figure 3 is an elevation view showing a first operating state of the model shown in Figure 2A.

[0017] Figure 4 is an elevation view showing a second operating state of the model shown in Figure 2A.

[0018] Figure 5 is an elevation view showing a third operating state of the model shown in Figure 2A.

[0019] Figure 6 is a schematic illustration of a vapor pressure management apparatus according to the present invention.

[0020] Figure 7 is a cross-section of a first embodiment of a vapor pressure management apparatus according to the present invention.

[0021] Figure 8 is a cross-section of a second embodiment of a vapor pressure management apparatus according to the present invention.

[0022] Figures 9A, 9B and 9C are plan views of a third embodiment of a vapor pressure management apparatus according to the present invention.

[0023] Figure 9D is an isometric view of the third embodiment of a vapor pressure management apparatus shown in Figures 9A, 9B and 9C.

Detailed Description of the Preferred Embodiment

[0024] As it is used in this description, "atmosphere" generally refers to the gaseous envelope surrounding the Earth, and "atmospheric" generally refers to a characteristic of this envelope.

[0025] As it is used in this description, "pressure" is measured relative to the ambient atmospheric pressure. Thus, positive pressure refers to pressure greater than the ambient

atmospheric pressure and negative pressure, or "vacuum," refers to pressure less than the ambient atmospheric pressure.

[0026] Also, as it is used in this description, "headspace" refers to the variable volume within an enclosure, e.g. a fuel tank, that is above the surface of a liquid, e.g., fuel, in the enclosure. In the case of a fuel tank for volatile fuels, e.g., gasoline, vapors from the volatile fuel may be present in the headspace of the fuel tank.

[0027] Referring to Figure 1, a fuel system 10, e.g., for an engine (not shown), includes a fuel tank 12, a vacuum source 14 such as an intake manifold of the engine, a purge valve 16, a fuel vapor collection canister 18 (e.g., a charcoal canister), and a fuel vapor pressure management apparatus 20.

[0028] The fuel vapor pressure management apparatus 20 performs a plurality of functions including signaling 22 that a first predetermined pressure (vacuum) level exists, "vacuum relief" or relieving negative pressure 24 at a value below the first predetermined pressure level, and "pressure blow-off" or relieving positive pressure 26 above a second pressure level.

[0029] Other functions are also possible. For example, the fuel vapor pressure management apparatus 20 can be used as a vacuum regulator, and in connection with the operation of the purge valve 16 and an algorithm, can perform large leak detection on the fuel system 10. Such large leak detection could be used to evaluate situations such as when a refueling cap 12a is not replaced on the fuel tank 12.

[0030] It is understood that volatile liquid fuels, e.g., gasoline, can evaporate under certain conditions, e.g., rising ambient temperature, thereby generating fuel vapor. In the course of cooling that is experienced by the fuel system 10, e.g., after the engine is turned off, a vacuum is naturally created by cooling the fuel vapor and air, such as in the headspace of the fuel tank 12 and in the fuel vapor collection canister 18. According to the present description, the existence of a vacuum at the first predetermined pressure level indicates that the integrity of the fuel system 10 is satisfactory. Thus, signaling 22 is used to indicate the integrity of the fuel system 10, i.e., that there are no appreciable leaks. Subsequently, the vacuum relief 24 at a pressure level below the first predetermined pressure level can protect the fuel tank 12, e.g., can prevent structural distortion as a result of stress caused by excess vacuum in the fuel system 10.

[0031] After the engine is turned off, the pressure blow-off 26 allows excess pressure due to fuel evaporation to be vented, and thereby expedite the onset of vacuum generation that subsequently occurs during cooling. The pressure blow-off 26 allows air within the fuel system 10 to be released while fuel vapor is retained. Similarly, in the course of refueling the fuel tank 12, the pressure blow-off 26 allows air to exit the fuel tank 12 at a high rate of flow.

[0032] At least two advantages are achieved in accordance with a system including the fuel vapor pressure management apparatus 20. First, a leak detection diagnostic can be performed on fuel tanks of all sizes, including large volume fuel tanks, e.g., 100 gallons or more. Second, the fuel vapor pressure management apparatus 20 is compatible with a number of different types of the purge valves, including digital and proportional purge valves.

[0033] Referring to Figures 2A and 2B, a model 100 of the fuel vapor pressure management apparatus 20 will now be described. The model relies on the principal of a standing column of liquid. Consider a cylindrical vessel 110 consisting of a container 112 with a freestanding cylindrical tube 114. The vessel 110 is partially filled with liquid 120 that separates the vessel 110 into a first chamber 122 and a second chamber 124. The first chamber is defined within the cylindrical tube 114, and the second chamber 124 is defined between the wall of the container 112 and the cylindrical tube 114. As shown in Figure 2A, the first chamber 122 is circular and the second chamber 124 is annular. The shapes of the chambers 122,124 in the model 100 may alternatively be defined by irregular or regular shapes other than circles, and may or may not share a common central axis A. The operation of this model will now be described.

[0034] Figure 2B shows a resting state of the model 100. In the resting state, the liquid 120 is at a level L, with respect to the bottom of the vessel 110, that is the same in both the first and second chambers 122,124. According to the model 100 shown in Figures 2A and 2B, the cylindrical tube 114 has an inside diameter d_1 and the container 112 has an inside diameter d_2. The vessel 110 is filled with the liquid 120 so that the cylindrical tube 114 is immersed to a depth of h_1. The volume of liquid below the cylindrical tube 114 is irrelevant. In the resting state, the model 100 will not allow vapor, e.g., air, to pass between the first and second chambers 122,124. In effect, the liquid 120 contiguously engaging the bottom end 114a of the cylindrical tube 114

creates a perfect seal. Flow will only occur through the model 100, i.e., between the first and second chambers 122,124, when a pressure or vacuum threshold is achieved as explained below.

[0035] Referring now to Figure 3, the pressure relief mode of the model 100 is enabled, when a positive pressure differential exists in the first chamber 122 relative to the second chamber 124. If a system to which the model 100 is connected, e.g., the fuel system 10, applies pressure to the first chamber 122, the column of liquid 120 within the cylindrical tube 114 is displaced until vapor escapes under the bottom end 114a into the second chamber 124. As positive pressure increases, the liquid 120 will be displaced from the cylindrical tube 114 into the annular volume of between the container 112 and the cylindrical tube 114. The start to flow pressure is governed by the head, h_2. The volume of the liquid 120 inside the cylindrical tube 114 in the resting state can be calculated as:

$$h_1 \times \pi(d_1/2)^2 \quad \underline{or} \quad h_1 \times A_1$$

where A_1 is the cross-sectional area inside the cylindrical tube 114. When the positive pressure differential reaches a level where the entire volume of the liquid 120 inside the cylindrical tube 114 has been displaced, vapor in the form of bubbles, as depicted in Figure 3, will be begin to escape from the first chamber 122. The level at which this pressure relief flow will begin to occur can be calculated by:

$$h_2 = h_1 + ((h_1 \times A_1)/A_2)$$

[0036] The pressure differential h_2 at which pressure relief occurs is dependent on the specific gravity of the liquid. As can be seen by this formula, the pressure relief point h_2 can be made significantly lower by increasing the difference in area between A_1 and A_2.

[0037] Vacuum sensing is depicted in Figure 4. An appropriate liquid level sensor 140 has been placed approximate halfway up the cylindrical tube 114. The level sensor 140 is active when the vehicle engine is OFF. If the system to which the model 100 is connected, e.g., the fuel system 10, applies vacuum to the first chamber 122, the column of liquid 120 within the cylindrical tube 114 is raised. The column of the liquid 120 can be detected by a number of methods (float, thermistor, capacitive, optical, conductive, etc.) when the liquid head reaches the detection threshold, h_3. The sensor 140 will signal a passing diagnostic when a negative pressure

differential that exists in the first chamber 122 relative to the second chamber 124 draws the liquid 120 up to the point of touching or triggering the level sensor 140. The vacuum sensing level or calibration is related to head differential between the first and second chambers 122,124, and to the specific gravity of the liquid 120. For example, at a given position of the level sensor 140, the vacuum sense calibration will increase with increasing specific gravity.

[0038] Vacuum relief is depicted in Figure 5. As vacuum continues to raise the column of the liquid 120 in the first chamber 120 to a higher level than in Figure 4, the liquid 120 will be displaced from the second chamber 124, under the bottom end 114a of the cylindrical tube 114, and into the first chamber 122. When the negative pressure differential reaches a level where the entire volume of the liquid 120 outside the cylindrical tube 114 has been displaced, i.e., to the bottom 114a of the cylindrical tube 114, vapor in the form of bubbles, as depicted in Figure 5, will begin to escape from the second chamber 124, under the bottom end 114a of the cylindrical tube 114, and into the first chamber 122. The level at which this vacuum relief flow will begin to occur can be calculate by:

$$h_4 = h_1 + ((h_1 \times A_2)/ A_1)$$

[0039] Figure 6 schematically illustrates a vapor pressure management apparatus 200 according to the present invention. Features having characteristics and functions that are similar to those of the model 100 are indicated with reference numerals that are incremented by one-hundred. Thus, for example, sensor 240 of the vapor pressure management apparatus 200 has characteristics and functions that are similar to sensor 140 of the model 100. Figure 6 also illustrates several additional features that will now be described.

[0040] The vessel 210 encloses the liquid 220 so as to contain the liquid 220 regardless of the orientation of the vapor pressure management apparatus 200. The liquid provides a means for controlling the direction of vapor flow, without a resilient element and without an electric element. Containment of the liquid 220 is in large part achieved by an inner partition 216 and an outer partition 218. The inner partition 216 establishes fluid communication path between a vapor port 226 and the first chamber 222, and the outer partition 218 establishes a fluid communication path between a vent port 228 and the second chamber 224. A first reservoir 232 is partially defined by the inner partition and the container 212, and a second reservoir 234 is

partially defined by the outer partition 218 and the container 212. The first and second reservoirs 232,234 provide holding volumes for any of the liquid 220 that may be displaced as a consequence of tipping or turning over the vessel 210. And at such time as the vessel is returned to its upright condition, the liquid 210 that was held in the first and second reservoirs 232,234 is returned to the first and second chambers 222,224 without being permitted to flow out either the vapor port 226 or the vent port 228. In this way, the liquid 220 that is placed inside the vessel 210 is contained in the vessel 210 regardless of changes in orientation of the vapor pressure management apparatus 200.

[0041] Referring now to Figure 7, there is shown a fuel vapor pressure management apparatus 300 according to a first preferred embodiment. Again, features having characteristics and functions that are similar to those of the model 100 or the schematic illustration of the vapor pressure management apparatus 200 are indicated with reference numerals that are incremented by two-hundred and one-hundred, respectively. Thus, for example, sensor 340 of the fuel vapor pressure management apparatus 300 has characteristics and functions that are similar to sensor 140 of the model 100, and to sensor 240 of the vapor pressure management apparatus 200. Figure 7 also illustrates several additional features that will now be described.

[0042] Vapor port 326 includes a fitting that is particularly suited to being mounted on the fuel vapor collection canister 18 of the fuel system 10 (Figure 1). The fuel vapor pressure management apparatus 300 includes a container 312 that can be mounted directly to the fuel vapor collection canister 18 by a "bayonet" style attachment 302. A seal (not shown) can be interposed between the fuel vapor collection canister 18 and the fuel vapor pressure management apparatus 300 so as to provide a fluid tight connection. The bayonet style attachment 302, in combination with a snap finger 304, allows the fuel vapor pressure management apparatus 300 to be readily serviced in the field. Of course, different styles of attachments between the fuel vapor pressure management apparatus 300 and the fuel vapor collection canister 18 can be substituted for the illustrated bayonet attachment 302. Examples of different attachments include a threaded attachment, and an interlocking telescopic attachment. Alternatively, the fuel vapor collection canister 18 and the container 312 can be bonded together (e.g., using an adhesive).

[0043] A semi-spherical portion 306 of container 312 contains the liquid 320 in the resting state of the fuel vapor pressure management apparatus 300. The inventors of the present invention have discovered that the semi-spherical shaped portion 306 reduces the impact of tilting from the vertical on the calibration of the fuel vapor pressure management apparatus 300.

[0044] Figure 8 shows an in-line style of connecting the fuel vapor pressure management apparatus 400 with the fuel vapor collection canister 18. Again, features having characteristics and functions that are similar to those of the model 100, the schematic illustration of the vapor pressure management apparatus 200, and the fuel vapor pressure management apparatus 300 are indicated with reference numerals that are incremented by three-hundred, two-hundred and one-hundred, respectively. The in-line style of connection includes a nipple 426 that can be interconnected with the fuel vapor collection canister 18 via an intermediate member such as a rigid pipe or a flexible hose (not shown).

[0045] Figures 9A-9D show a fuel vapor pressure management apparatus 500 according to a third preferred embodiment of the present invention. Again, features having characteristics and functions that are similar to those of the model 100, the schematic illustration of the vapor pressure management apparatus 200, and the fuel vapor pressure management apparatuses 300 and 400 are indicated with reference numerals that are incremented by four-hundred, three-hundred, two-hundred and one-hundred, respectively. The fuel vapor pressure management apparatus 500 includes a bayonet-style attachment 506 for coupling to the fuel vapor collection canister 18. Notably, the fuel vapor pressure management apparatus 500 uses non-circular walls to separate and partition the first and second chambers 522,524, and uses fewer components so that the cost of manufacturing is reduced.

[0046] With regard to the liquid 120,220,320,420,520, increasing the specific gravity of the liquid will reduce the physical size of the device. For example, increasing the specific gravity of the liquid reduces the displacement (i.e., h_4 in the case of vacuum relief) of the liquid column necessary to achieve the same vacuum level at the point of relief.

[0047] Preferably, the viscosity of the liquid 120,220,320,420,520 is heavy enough that the bursting bubbles to not spray liquid into the air stream to be carried away. Liquid traps may be used to capture and retain the liquid so as not to drain out of the container 112,212,312,412,512

if the vessel 110,210,310,410,510 is tilted or overturned. A liquid trap can include partitions, baffles, etc. that direct the flow of the liquid way from the ports. A, tortuous path can also be implemented to keep the liquid inside the vapor pressure management apparatus. Preferably, the viscosity remains fluid enough to enable the apparatus to operate at extreme low temperatures.

[0048] For the device to be viable over the life of a vehicle, the liquid needs have a very low evaporation rate and must not freeze into a solid until at least -40° Celsius. According to the present invention, a preferable liquid should possess the following properties:

- Excellent oxidative and thermal stability
- Low volatility and vapor pressure
- Non-flammable and chemically inert
- Excellent plastic and elastomer compatibility
- Resistant to aggressive chemicals and solvents

Low evaporation is required so that that apparatus function can be maintained over a 15-year and 150,000-mile life of a vehicle. In addition, a low evaporation rate ensures that the liquid itself will not create stray airborne hydrocarbon molecules that could fail an evaporative emissions test. A preferable liquid will have a kinematic viscosity range of 75-600 centistokes throughout a temperature range of –40 to +100 degrees Celsius, and will have a near zero vapor pressure ($\sim 5 \times 10^{-9}$ torr at 100 degrees Celsius).

[0049] A synthetic oil, such as Fluorinated Polyether, is an example of an acceptable liquid. Preferably, the liquid may be Perfluoropolyether (PFPE), which has an acceptable viscosity and may be used in extreme temperature environments or in applications that require chemical, fuel, or solvent resistance.

[0050] The liquid may also include suspended carbon particles to act as an electrical conductor, or the liquid may include glass micro-spheres to thicken the liquid and prevent splashing and liquid carry-over.

[0051] With regard to the sensor 140,24,340,44,540, the vacuum sensing 22 can be accomplished with a positive or negative temperature coefficient thermistor, a capacitive sensor, a float and a contact switch, a magnet and a reed switch, resistive/conductive oil, and many

others. These devices can be used to sense the liquid level of the column in the first chamber. For example, the presence or absence of the liquid at a level can be sensed using a heated thermistor that dissipates more heat in liquid than in air, or with a capacitive sensor inasmuch as oil and air have very different dielectric constants. Further, sensors that measure that directly measure the pressure differential that causes liquid displacement can also be used in conjunction with the vacuum relief and pressure blow-off the pressure differentials between the first and second chambers.

[0052] Numerous advantages are achieved in accordance with the vapor pressure management apparatus according to the present invention. These advantages include providing a leak detection diagnostic using vacuum monitoring during natural cooling, e.g., after the engine is turned off, providing relief for vacuum below the first predetermined pressure level, and providing relief for positive pressure above the second predetermined pressure level. Additionally, the vacuum relief 24 provides fail-safe purging of the canister 18, and the relieving pressure 26 regulates the pressure in the fuel tank 12 during any situation in which the engine is turned off, thereby limiting the amount of positive pressure in the fuel tank 12 and allowing the cool-down vacuum effect to occur sooner.

[0053] According to the present invention, the liquid has the ability to wet-out on the walls and effectively lower the volume that has to be displaced, and to lower the back-pressure because the liquid clings to the walls and out of the path of airflow. The liquid also acts as a wet filter to remove debris from the incoming air stream.

[0054] The present invention advantageously includes a semi-spherical shaped lower housing that reduces the impact of tilt angle on calibration. A spill-proof housing uses tortuous paths and reservoirs to contain liquid in the event that the part is inverted, and then the liquid returns to its original location when part is set upright. Further, a reservoir of unused liquid can be provided to top up the liquid level if there is a liquid loss due to evaporation or liquid carry-over. And if liquid becomes contaminated or destroyed, a service procedure could be created to rejuvenate the part by extracting the used liquid and inject a replacement amount of new liquid.

[0055] It is also possible according to the present invention to take advantage of the meniscus effect on the cylindrical tube end. This will tend to create a higher than expected level of

pressure or vacuum relief. Also, the meniscus effect can be used to make the device smaller than expected.

[0056] According to the present invention, installation options include in-line and canister mounted variations. The vapor pressure management apparatuses according to the present invention also inherently provide zero vacuum leakage, allow positive and negative pressure relief values to be designed by geometry, presents no mechanical moving parts and thus there is no wear, no filtration is required, reduced durability testing, no calibration is required, and a very low parts count to ease assembly and reduced manufacturing costs.

[0057] While the present invention has been disclosed with reference to certain preferred embodiments, numerous modifications, alterations, and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it have the full scope defined by the language of the following claims, and equivalents thereof.